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Method and Device for Identifying a Drop in Pressure and for  
Controlling Dynamics of Vehicle Movement

The present invention relates to a method and a device for pressure loss detection and for driving dynamics control.

In conventional pressure loss detection methods, one or more test quantities are determined with respect to most different signals, among these sensor signals and intermediate quantities from other vehicle components. The test quantities may e.g. be compared with threshold values to infer therefrom pressure conditions in the tires of the vehicle. Pressure loss detection can be effected individually for each wheel or for several or all wheels of the vehicle (for example, development of the quotient of the sum of the wheel speeds on the diagonal and comparison of the quotient with thresholds). Besides, tire pressure loss detection operations are usually based on a comparison between the vehicle speed (e.g. vehicle reference speed) and angular speeds (that can be detected by sensors) of the individual wheels. The relationship  $w = v/r$  applies in this respect, wherein  $w$  designates the angular speed,  $v$  the vehicle speed (speed of the wheel axle), and  $r$  the dynamic tire-tread circumference which is smaller in tires with pressure loss than in regular tires.

Tire loss detection is affected by various disturbances, for example, by different running speeds of wheels in cornering maneuvers (see e.g. Figure 3: the wheels 31, 34 of the vehicle 30 on the outside curve move by approximation on the radius  $R_a$ , while the wheels 32, 33 move on the smaller radius  $R_i$  so that they must cover a shorter distance in the same time and, hence, must cover less rotations). Other mechanisms which are caused

by the driving dynamics of the vehicle will also lead to distortions (e.g. brake slip or traction slip, wrong signals when the vehicle is oversteered or understeered) so that inaccurate detections and especially faulty detections can occur.

It is partly possible to systematically compensate for errors by selecting the detection algorithm or by employing learned correction value tables. However, especially in high-dynamics driving maneuvers, this measure is not sufficient to prevent faulty detections with a sufficient rate of safety.

On the other hand, the tire pressure conditions also influence the quality of driving dynamics control systems such as anti-lock system, electronic stability control, traction slip control. The mentioned control systems mostly make use of the vehicle brakes, sometimes also the vehicle engine, as control elements and adjust there defined conditions, such as brake pressures, brake pressure gradients, wheel slip, engine output torque, etc., corresponding to the desired objective of the control. All these control interventions take place at least under the assumption that the force transmission between vehicle and wheel, on the one hand, and the roadway, on the other hand, is not disturbed at the vehicle end (at the roadway end it may e.g. be disturbed by slick ice). However, the above assumption is not correct when one or more tires of the vehicle suffer from pressure loss. Force transmission is disturbed then, only lower forces can usually be transmitted. In the end, the result is that the mentioned regulation and control systems are wrongly conformed to the actual conditions. This is disadvantageous per se. In addition, unsymmetrical force transmissions may e.g. cause unexpected unstable driving conditions which is even dangerous.

An object of the present invention is to disclose a method and a device for pressure loss detection and for driving dynamics control which take into account the interactions between tire pressure and driving dynamics especially in driving maneuvers with a high driving dynamics.

This object is achieved with the features of the independent claims. Dependent claims are directed to preferred embodiments of the present invention.

Pressure loss detection according to the present invention operates as a function of at least one driving dynamics variable. When the driving dynamics variable satisfies determined conditions, pressure loss detection can be influenced according to predetermined patterns. Predetermined correction values or correction algorithms can be used to this end. 'Predetermined' in this context means that the values are correction values or correction strategies available from the very beginning rather than values learned during operation of the vehicle. The correction values or correction strategies may be employed especially in driving maneuvers with a high driving dynamics, for example, when the longitudinal acceleration is  $> 0.1 \text{ g}$ , preferably is  $> 0.2 \text{ g}$ , and/or when the transverse acceleration is  $> 0.2 \text{ g}$  or  $> 0.3 \text{ g}$ , and/or when the wheel slip on at least one wheel is  $> 4 \%$ , preferably is  $> 6 \%$  (traction slip and brake slip).

One or more of the following quantities can be taken into account as driving dynamics variables: the vehicle speed, e.g. the vehicle reference speed as it is produced by defined algorithms from the wheel speeds, the longitudinal acceleration which is either determined from the vehicle reference speed by way of calculation or detected by sensors, the yaw rate (angular speed about the vertical axis), either detected by

sensors or calculated, the transverse acceleration (detected by sensors or calculated), the steering wheel angle, in general a curve characteristic value (e.g. calculated curve radius), a wheel acceleration, especially a wheel angle acceleration as it can be derived from the wheel signals of the wheel sensors, for example, the wheel slip (difference between wheel (roadway) speed and vehicle reference speed), the wheel slip gradient (derivative of the wheel slip, wheel slip acceleration), the tire side wall torsion, e.g. detected by sensors.

One or more of the above quantities can be checked for the existence of defined conditions with respect to their values and also with respect to their time variation. When these conditions apply (value condition and, as the case may be, additionally time condition), modification of the pressure loss detection can occur.

Driving dynamics control according to the present invention also takes place in dependence on the tire pressure conditions found. The tire pressure conditions can affect the nominal values specification, the thresholds of response, or the selection of control strategies.

When the wheel suffering from the loss in pressure is known, modifications in the control strategy can be taken for this wheel only. In addition, modifications can be effected in this case also on another wheel for the compensation of forces.

When the wheel suffering from pressure loss is unknown, modifications can be effected for all wheels.

In general, lower nominal pressure values, nominal pressure gradients, wheel slip values, or drive torques can be predetermined as nominal values or adjusted by the control in

the event of pressure loss. The pressure loss detection for influencing the driving dynamics control can be performed as described hereinabove.

Individual embodiments of the present invention will be described in the following by making reference to the accompanying drawings. In the drawings,

Figure 1 is an embodiment of the pressure loss detection according to the present invention.

Figure 2 is a more detailed embodiment of Figure 1.

Figure 3 is an explanation with respect to disturbances.

Figure 4 is a driving dynamics control system according to the present invention.

Figure 5 is a combined system made up of driving dynamics control and pressure loss detection.

Figure 1 shows a pressure loss detection device according to the present invention. The actual detection takes place in the device 11 which may generally have a conventional operation. Pressure loss detection 11 receives input signals 13 and outputs output signals 15. Input signals 13 may comprise sensor signals, intermediate quantities from other vehicle components, and other data. Output signals 15 may comprise alarm signals, control signals for other device components, and information signals with respect to tire pressure. A test quantity PG can e.g. be determined as follows in the pressure loss detection:

$$PG = ((wvl + whr) / (wvr + whl)),$$

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wherein  $w_{vl}$  designates the left front wheel speed,  $w_{vr}$  designates the right front wheel speed,  $w_{hr}$  the right rear wheel speed, and  $w_{hl}$  the left rear wheel speed. In the ideal case (constant velocity of all wheels, identical diameter of all wheels), the test quantity is 1, discrepancies herefrom may hint at a tire which is smaller due to the tire pressure and, hence, runs faster. The test quantity  $PG$  is compared to threshold values, and in the event that it exceeds or drops below the threshold values, a pressure loss is detected and appropriate signals are output.

Reference numeral 12 designates a modification device which receives input signals 14 that mirror one or more driving dynamics variables. Device 12, in turn, produces signals which permit influencing the pressure loss detection 11.

Pressure loss detection can be influenced in most different ways. This is shown in more detail in Figure 2. The detection device 11 has a detection element 21 with a determining device 22 that determines a test quantity, for example, as indicated hereinabove, and a checking device 25 which checks the test quantity by way of threshold values, represented by reference numeral 26. One or more signals are output when defined conditions prevail. The modification device 12 can have an effect on the detection in different ways. It can e.g. modify the input signals when pressure losses exist. This is represented by selector switches 23b, 23c and modification devices 24b, 24c which are actuated or set and adjusted according to the modification device 12.

The modification device 12 can also influence or change the algorithm used in the determining device 22. When e.g. traction slip prevails, provisions can be made that the test quantity is no longer determined with respect to the driven wheels, or that

other values (e.g. those of the non-driven wheels) are used for the said wheels.

It is also possible to modify the test quantity itself, as it was determined by the determining device 22. This is indicated by selector switch 23a and modification device 24a that are actuated according to the modification device 12. It is also possible to prevent tire pressure testing at all. This is indicated by interruption of the output by means of switch 20 which is likewise actuated according to the modification device 12.

Besides, it is also possible to change a threshold value which is taken into account for the detection by e.g. writing a different value into the memory 26.

The mentioned measures can be employed individually and in combination with each other. In the modification device 12, there is a logic 29 which receives the driving dynamics data 14a-14d and, according to said, generates suitable actuation signals for influencing the pressure loss detection according to one or more driving dynamics variables. The modification device 12 may also include a memory 28 which can comprise e.g. tables for correction values, wherein access is made to the tables according to a driving dynamics variable, and the read-out value is used for the correction of an input signal 13a, 13b or for the correction of the test quantity. The correction value can be used additively or multiplicatively, or as a replacement value. This way, input quantities 13a, 13b, intermediate quantities such as the test quantity PG, or threshold values can be changed, corrected, or replaced.

Pressure loss detection can also be rated so that method steps are permanently taken corresponding to a modification (with or

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without pressure loss), that, however, the modification is neutral (e.g. multiplication with 1, addition of 0) in the event of absence of pressure loss. This is advantageous because in the event of pressure loss, only the quantity used for correction rather than a corresponding algorithm must be changed in the case of pressure loss.

Beside the qualitative detection signals indicated in Figure 2, the determining device 22 can also produce data signals, for example, data representing the wheel diameter differences of the individual wheels. Said data, too, can be modified according to driving dynamics and output, as the case may be.

A side wall torsion sensor at the wheel tire furnishes a signal which is especially favorable for the present purposes. The result of acceleration and deceleration operations and lateral forces is that the side wall of a tire displaces and twists in a circumferential direction and in a radial direction and, as the case may be, also in an axial direction of the wheel. This will occur to a particularly great extent in tires with pressure drop. When the side wall torsion is detected by sensors, this signal can be taken into account for determining the wheel dynamics and then indirectly for influencing the tire pressure detection, or it is taken into account directly for pressure loss detection, for example, when the torsion exceeds a certain degree.

Learning operations can also occur within the above-mentioned direct modification, for example, for determining correction values during operation of the vehicle which are adapted still better than factory-adjusted correction values. To store such learned correction values, memories can be provided which preserve any information inscribed in them, even in the event that their input voltage gets lost.

If driving dynamics sensors show redundancies, the signals with the highest resolution can be chosen.

In general, the input signals required and the output signals generated can be taken from a data bus or introduced into the bus, for example, a CAN bus. The driving dynamics variables employed may be sensor quantities, filtered sensor quantities, or data that is already preassessed.

Figure 4 shows a driving dynamics control according to the present invention comprising at least one controller 41 which receives input signals 43 and outputs output signals 45. Part of the input signals 43 will be measuring signals from the controlled system (wheel sensors, acceleration sensor, transverse acceleration sensor, yaw rate sensor, steering angle sensor, or like sensors). Likewise, other input signals can be received, for example, quantities from other operations. A part of the output signals 45 will be actuation signals for control elements, for example, for the wheel brakes, hydraulic pumps, for an engine interface, or similar elements. The controller may represent a brake control, and/or a traction slip control, and/or an electronic stability control. The systems may operate a priori according to conventional algorithms.

Reference numeral 42 represents a pressure loss detection device which generally detects the existence of a pressure loss in a special wheel or in any wheel of the vehicle. The pressure loss detection 42 can be configured as described hereinabove.

The pressure loss detection 42 generates signals which modify the operation of the controller when pressure loss is detected. The modification can refer to the input quantities 43, the

output quantities 45, or parameters or algorithms for processing the input data and for generating the output data.

When a wheel suffers from pressure loss, it is a priori desirable to load it less as far as acceleration forces and brake forces are concerned. Accordingly, it can be desirable to have lower brake forces or gradients hereof adjusted by the control for such a wheel. The same applies with respect to acceleration forces. To reach this aim, lower brake pressure values, or brake pressure gradients or engine torques, or engine torque gradients can be adjusted by the control.

Insofar as the wheel with pressure loss is precisely known, this modified control can relate to the known wheel alone. For force compensation purposes, any other wheel, e.g. the diagonally opposite wheel, can also be controlled similarly in a modified fashion in this case. When the wheel with pressure loss is unknown, all wheels can be controlled in a modified fashion.

If a vehicle is equipped with an automatic transmission or (in all-wheel drive) a center clutch with automatic intervention, these control elements may also be used for driving dynamics control. When the pressure loss is detected, for example, clutches or lock differentials in the drive train of the corresponding wheel or the respective axle can be opened or only partly closed. This applies especially to the case of traction slip control.

It is particularly favorable when the driving dynamics control described hereinabove is integrated in conventional systems for cooperation. This means in particular that the system of the present invention does not act 'in competition' with conventional systems. Rather, it is advantageous that the

driving dynamics control according to the present invention is integrated algorithmically in conventional control systems so that it can operate along with a conventional control by using the same hardware.

Figure 5 shows a combined embodiment of pressure loss detection and driving dynamics control. Like reference numerals as in the previously referenced drawings imply identical components which shall be explained herein again only as far as required. Among others, the controller 41 receives certain signals 15 from the pressure loss detection 11. The signals do not have to be exclusively signals output by the pressure loss detection 11.

The signal trains 13, 14, and 43 drawn separately in Figure 5 may comprise or designate the same signals, at least in part. This may also, at least in part, concern the access to a bus where the necessary data prevails, for example, cyclically.

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